research review

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DETONATION IN HIGH-PRESSURE GAS MIXTURES

DR. ROBERT G. DUNN, Fluid Dynamics Facilities Laboratory, ARL

The characteristics of detonation in gaseous mixtures at atmospheric pressure have received much attention in the past. Theoretical treatment has been extended to quite high pressures for a variety of gaseous mixtures. In a few instances, such as hydrogen-oxygen mixtures, experimental studies have also been pushed to fairly high pressures. However, in most cases the experimental results have been obtained at initial pressures limited to only a few atmospheres. In an in-house study recently completed at ARL, an effort was made to relate theory and experiment for high-pressure detonation in hydrocarbon-oxygen mixtures, particularly over a wider pressure range than heretofore investigated. Consideration of hydrogen-oxygen mixtures was also included for comparison. The model of gaseous detonation chosen for investigation was essentially the Zeldovich-von Neumann-Doering idealized hydrodynamic model (plane wave, ideal gases, chemical and thermal equilibrium, no energy losses). The results of this effort are described in a technical report now in the process of publication at ARL. This material was submitted recently in partial fulfillment of the requirements for the Ph.D. degree in the Graduate School of Ohio State University.

Although of great interest per se, as a highly transient, remarkably reproducible gasdynamic phenomenon reasonably amenable to laboratory experimentation, the detonation process and basic studies related to it are of much more than academic interest. The ultimate objective of an investigation involving gaseous detonation may be a potential advantageous application, or it may be the avoidance of destructive effects. In either case, a thorough knowledge of the basic chemical and gasdynamic processes occurring in the detonation of gaseous mixtures is of fundamental importance. Combustion processes at high pressure, including detonation, have been employed or considered for use in the driver and/or buffer sections of shock tubes used in aerodynamic research. These processes are also being investigated for application in the driver section of hypervelocity launchers used in laboratory free-flight experimentation. On the other hand, in many instances where gaseous mixtures being handled are combustible, the primary

concern is the avoidance of detonation. Consideration of chemical techniques for producing high temperatures for hypersonic wind tunnels, under high-pressure conditions which may be conducive to detonation in the working medium, falls in this category. Other examples are chemical processes in industrial plants, and combustible air-vapor mixtures sometimes formed in compressed air storage and handling systems or large ducts. When detonation has occurred in some of these cases, it has resulted in extensive destruction of facilities and equipment.

Originally, it was intended to attempt experimental measurements of several detonation parameters in order to determine if the chosen detonation model could be verified or disproven. Detonation velocity, pressure, and temperature were selected initially for this experimental observation. A method for the measurement of detonation static temperatures has now become commercially available, but was too late for use in this investigation. Original plans for the measurement of detonation velocity and pressure, however, were carried out, with the pressures being limited to the "steady" values occurring in the Chapman-Jouguet region of the wave. Computation of detonation parameters for each gaseous mixture was made over a 2,000-fold range of initial pressures, specifically 0.5 to 1,000 atmospheres, utilizing the 7090 digital computer. Experimental measurements of detonation velocity were made in a uniform-diameter (1-1/2") tube to as high initial pressures as considered feasible--20 atmospheres in most cases, but as high as 50 atmospheres in some instances. Also, static pressures in the detonation wave were measured; but this was done for only a limited number of mixtures and only in the lower range of initial pressures.

The observed and calculated detonation velocities obtained were in very good agree-

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JACOB SEIDEN
Editor

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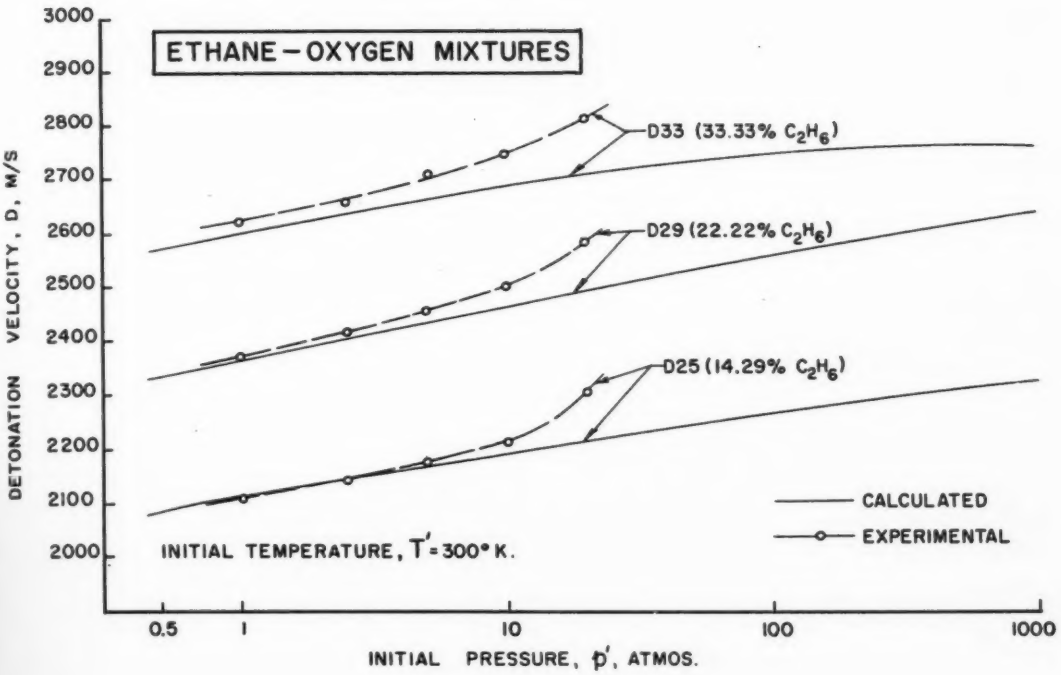

Calculated and Experimental Detonation Velocities for Ethane-Oxygen Mixtures

ment for all mixtures and initial conditions investigated where the wave had attained a steady velocity. The experimental and calculated detonation static pressures were in extremely good agreement, based on mean values of experimental pressure observed, although the uncertainty of the pressure measurements was more than ± 10 per cent in most cases. Based on the quite precise detonation-velocity results obtained, it was concluded that the dissipating effects due to heat losses and friction are very small in most cases. At nearly all of the conditions investigated, particularly at the higher initial pressures (approximately 5 atmospheres and above), these effects were completely masked by other factors tending to cause the experimental detonation velocity to exceed the calculated value. Departure from ideal gas behavior was found to be the principal factor causing deviation of experimentally observed detonation velocities from the theoretical values obtained in accordance with the postulated detonation model. In general, deviation between theory and experiment was found to increase with increasing initial pressure, with experimental detonation velocities as much as 2.6% higher than the theoretical values at initial pressures near 10 atmospheres. Typical results are shown in the accompanying figure.

Two general conclusions were reached: (a) At initial pressures near atmospheric, the effects of nonideality in the initial and final mixtures are extremely small and cause negligible differences between actually observed detonation characteristics and those predicted on the basis of the idealized theoretical model described in this study. (b) At the higher pressures--between approximately 5 and 50 atmospheres in this investigation--the simple hydrodynamic theory and the postulated model describe (probably most) gaseous detonations extremely well, with the exception of the deviation from ideal gas behavior of the product gases. ★

FORECASTING IN SPACE

SPACE PHYSICS LABORATORY, AFCRL

AFCRL has begun a major new program having as its goal the prediction of conditions likely to be encountered in the space environment. The clues that may lead to precise forecasting are being sought by AFCRL scientists in the masses of environmental data collected by hundreds of AFCRL sensors all over the world. AFCRL will attempt to predict changes or events relating to the eath's airglow, auroral activity, proton emissions from the sun, the earth's magnetic field, and levels of ion and electron concentrations in the earth's radiation belts and ionosphere.

These phenomena have all been investigated at AFCRL for many years--but largely as isolated aspects of the environment. Still they are related in one common particular: all are controlled or modified in some way by the sun. The recognition of such solar influence gave rise in 1957-1958 to the IGY and to the present IQSY. In both of these international cooperative efforts, thousands of measurements of the sun and solar-induced phenomena are involved.

In this sense, the new AFCRL program has an IGY-IQSY flavor. The differences are that the AFCRL effort will concentrate on prompt data reduction and analysis, and has the well-defined goal of evolving forecasting techniques. The program is conducted by a group of about 20 people--8 of them assigned to AFCRL from the Air Weather Service. Specifically, they are assigned to the recently established Space Forecasting Branch of AFCRL under the direction of Eugene E. Duff.

AFCRL is in a unique position for research in this field. With its contractors, AFCRL operates more than 100 environmental-data-gathering sites all over the world, it instruments 30 to 40 rocket probes each year, and it designs instrument packages for placement aboard Air Force and NASA satellites. AFCRL operates the Sacramento Peak Solar Observatory in New Mexico, one of the world's leading solar observatories, and fully supports the Ft. Davis Radio Observatory in Texas with its two 60-foot radio telescopes. At its own Sagamore Hill Observatory in Hamilton, Mass., it operates an 84-foot radio telescope and a 150-foot radio telescope. In addition to all these sensors and sensor-carrying vehicles, it has a large research-balloon-development program providing yet another type of vehicle for transporting packages above most of the earth's atmosphere, for a clearer view of space. Finally, AFCRL operates 5 highly instrumented aircraft which fly on data-collection missions from the arctic to the antarctic.

Sensors located at ground-based sites, or carried aboard vehicles into the upper atmosphere and the near-space region, range from simple riometers to the huge solar and radio telescopes operated by AFCRL. Within this range are a multitude of magnetometers, mass spectrometers, ultraviolet and infrared spectrometers, ion guages, backscatter radars, and other equipment.

These sensors, facilities and vehicles, together with AFCRL's experience and capability in the environmental sciences, place AFCRL in a unique position for environmental forecasting research. Only one basic difficulty had to be overcome before the new Space Forecasting Branch could function properly. Because data are often perishable, they must be received and analyzed without the delays often inherent in the data-analysis process.

To obtain photographs of the sun and its rapidly changing features from the Sacramento Peak Observatory, a photographic link between the Observatory in New Mexico and

the Forecasting Branch in Bedford, Mass., is being set up. Within minutes, photographs taken at Sacramento Peak will be available in Massachusetts.

To achieve the prompt decommutation of telemetered data from rockets and satellites, AFCRL has installed special decommutation equipment. Not only has decommutation equipment been installed, but radio receiving equipment is also being constructed to obtain satellite data directly for reduction on a real-time basis.

As an intrinsic part of the Branch's role as a focal point of Air Force environmental data, the Branch will compile these data for broad dissemination. It has inaugurated a new quarterly publication, Geophysics and Space Data Bulletin, devoted to environmental-sensor data. This bulletin will be made available on request.

The heart of the new program will be a forecasting workshop under the scientific guidance of Dr. F. W. Ward, Jr. Within this workshop, AFCRL scientists hope to uncover the essential correlations that will provide the clues to predictions--predictions which may hopefully be extended to longer and longer time periods. Initially, the workshop will concentrate on methods for forecasting the occurrence of solar flares and auroral events. ★

Members of AFCRL's new Space Forecasting Branch surround Anne Carrigan, editor of the new AFCRL publication, Geophysics and Space Data Bulletin. Head of the new Branch is Eugene Duff, standing behind Miss Carrigan. Eugene Duff is author of the item, "Forecasting in Space," appearing in this issue of the OAR Research Review. Standing next to Mr. Duff is Major Thomas Douthit, recently appointed Chief of the Space Physics Laboratory, parent unit of the new Space Forecasting Branch. Seated beside Miss Carrigan is Dr. Frederick Ward who will provide technical guidance for the forecasting workshop aspect of the Space Forecasting Branch. On the right is Harold E. Lyons, communications specialist. In the background is equipment recently installed for the decommutation of telemetered data from rockets and satellites.

excitons in the photoconductivity of CdS

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Recently, exciton structure has been observed in the photoconductive spectral-response curves of a number of II-VI-compound semiconductors grown in this laboratory. It has been observed that a number of peaks in the photoconductivity spectra of CdS, CdSe and ZnSe single crystals correspond to the exciton spectra identified by other optical measurements. Many crystals exhibit photoconductivity peaks at energies corresponding to the positions of free excitons. Some crystals show, in addition to this, an oscillatory photoconductivity in the higher-energy side of the absorption edge.

In CdS, the fundamental absorption bands consist of three exciton series associated with three levels of the valence band. Each of the bands can give its own group of exciton levels near the conduction band. The exciton series associated with the first valence band is termed the "A" exciton series, and the series associated with the second and third valence bands are termed the "B" and "C" exciton series, respectively.

Within a given series, the lines form nearly hydrogen-like energy spacings. The ground state of each series is the $n = 1$ state of the hydrogen-like energy levels where n is the principal quantum number. The $n = 2, 3, 4...$ states represent the excited states of each exciton series.

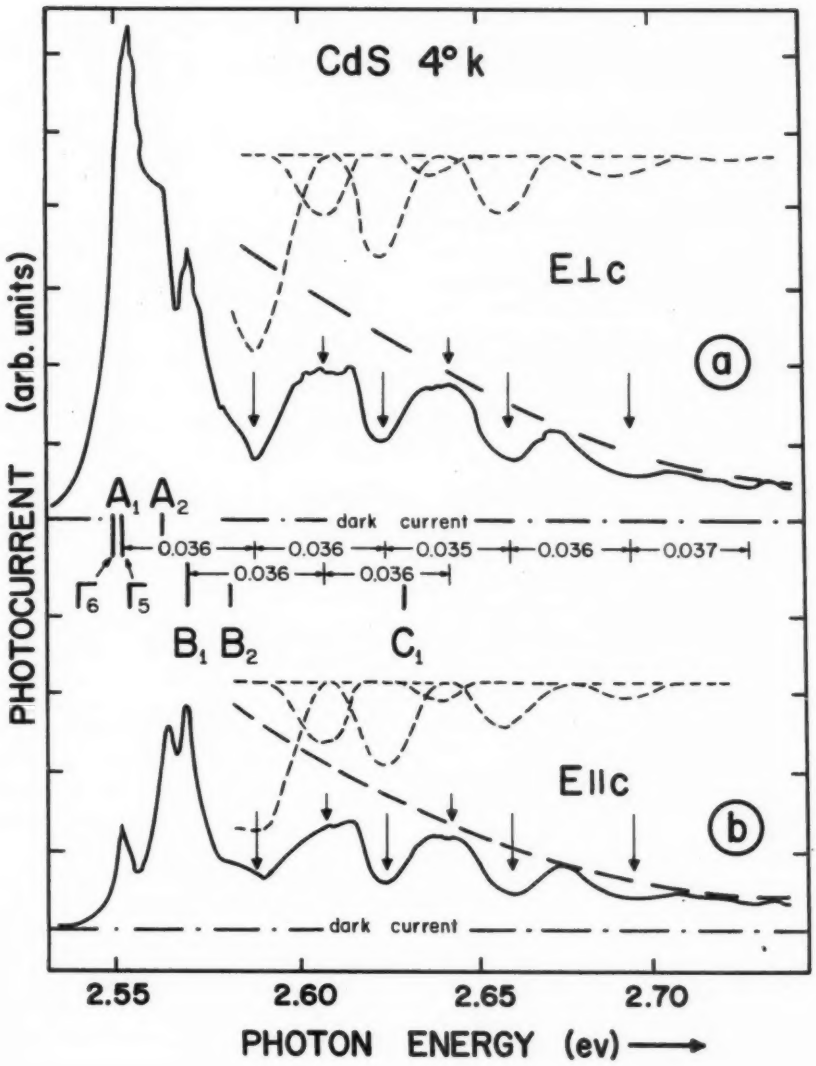
The two-part figure below shows spectral response curves of photocurrent of CdS at 4.2°K. Figure (a) is recorded with the E vector of the exciting light polarized perpendicular to the c axis of the crystal, and Fig. (b) for light polarized parallel to the c axis. Indicated by bars are the positions of A, B, and C. The photoconductivity peaks (A_1 = 2.554 eV) corresponding to the $n = 1$ state of exciton A is only active in $E \perp C$. The peaks corresponding to the $n = 2$ state of exciton A (A_2 = 2.575 eV) and the $n = 1$ and $n = 2$ states of exciton B (B_1 = 2.569 eV, B_2 = 2.591 eV) are seen in both modes of polarization. The oscillatory structure is indicated by long and short arrows. A series of minima, indicated by long arrows, is spaced successively by 0.036 eV from A_1 exciton peak, and the B series, originating from the B_1 exciton peak by exactly the same, is indicated by short arrows. The energy spacing of 0.036 eV corresponds to the longitudinal optical phonon energy at the zone boundary. The dashed curves show the separated contributions of the processes covering A and B minima.

From the appearance of peaks on the spectral curve of photocurrent in the region of fundamental absorption, one can certainly conceive two mechanisms of photocurrent generations: (1) the direct formation of free electrons and holes, and (2) the creation of free carriers through excitons. The existence of a background and the observation of the series limit on the spectral curve can easily be comprehended if one assumes a band-to-band transition, i.e., a direct excitation of electrons from the valence band to the conduction band. On the other hand, from the fact that the largest part of the sensitivity is concentrated in the regions of the exciton absorption lines, the contribution of excitons to photoconductivity is apparent and large.

Of course, excitons themselves, having a neutral charge, cannot contribute directly to the electrical conductivity. Excitons must dissociate in order to make a contribution to the photocurrent. The following mechanisms for production of free carriers via exciton states can be envisioned:

(1) The dissociation of excitons through interaction with phonons.
(2) The dissociation of excitons through interaction with impurity centers.
(3) The dissociation of excitons through interaction with excitons.

For the first mechanism to occur, the exciton need not necessarily be mobile. The second and third mechanisms naturally assume the motion of excitons. There is no direct experimental evidence to establish

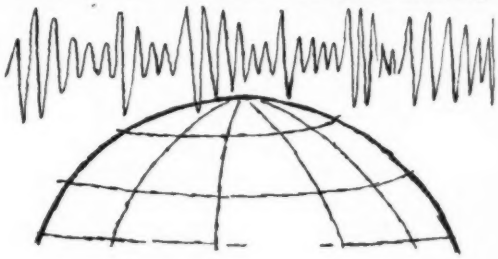


whether excitons in fact are mobile in these materials. An experimental attempt to observe the diffusion of excitons in the photoconductivity phenomena of CdS was undertaken by several workers. However, this experiment has been subjected to criticism and controversy. Though a direct observation of the movement of an exciton has never been achieved, there are many experimental observations which cannot be comprehended without assuming the motion of excitons.

Before interpretation can proceed much further regarding possible mechanisms of exciton participation in photoconductivity, theoretical work should be advanced in order to clarify what has been found and to point the way for further investigations. Although a direct observation of the movement of the exciton, say, from its place of creation to its place of annihilation, may be difficult, future experimental investigation should be directed toward verifying such movement. Photoconductivity measurements at lower temperatures than 4.2° K may help to decide whether the dissociation of excitons by thermal energy is a primary process. ★

WORLD-WIDE SURVEY OF SMALL EARTHQUAKES

MAJ ROBERT A. GRAY & HENRY A. OSSING
Terrestrial Sciences Laboratory, AFCRL



AFCRL recently published the first comprehensive study of world-wide earthquake activity in the same magnitude range as that of the seismic disturbances produced by nuclear explosions. This study was conducted for AFCRL by Texas Instruments, Inc., as part of VELA UNIFORM, the underground nuclear-test-detection program of the Advanced Research Projects Agency.

Until this study was performed, the most comprehensive study of world-wide seismicity was the one performed by Gutenberg and Richter in 1954. However, they only considered events of magnitude 6.0 or greater, and extrapolated downward to estimate the number of events of lesser magnitude occurring each year. Since most underground nuclear tests will register on seismograms as events of magnitude 5.0 or less, it was highly desirable to determine the number, geographical location, and frequency of occurrence of shallow-focus earthquakes which might be confused with underground explosions.

Data from 61 seismograph stations all over the world were processed, and more than 4,000 earthquakes investigated. These data were then reduced and presented in the form of tables and maps which make up the bulk of the report. For the purposes of the study, the earth was divided into 22 regions on a political-geographical basis. A table giving date, time, location, depth, and magnitude of each earthquake studied, and 3 maps of seismicity, were included for each region. One map gives the location of each earthquake's epicenter, the point on the earth's surface directly above the place underground where an earthquake occurs; another, the number of earthquakes in the nuclear-explosion-magnitude range occurring per unit area (about 300,000 sq km) per year; and the third, the energy released per unit area by these earthquakes. Three maps of world-wide seismicity are also presented in this form.

The greater portion of the work in this study involved the calculation of magnitudes. This was due in part to the variety of methods that exist for calculating earthquake magnitudes depending on the type of shock wave measured (and therefore on the type of instrument used), distance of recording station from the earthquake, and depth of the earthquake. However, since all methods use the maximum excursion of the seismograph needle during an earthquake as the basic parameter, it is possible to calculate a weighted average magnitude for an earthquake from several methods. The report lists 13 methods by which this was done for each earthquake studied.

The study concludes that 1960 was more seismic than average. Not only does the world-wide level of seismicity vary from year to year, but the percentage of the earth's seismic activity contributed by each region also varies from year to year. Definition of the seismicity of the USSR was lacking in completeness; but it was found that not more than five per cent of earthquakes in the magnitude range of seismic disturbances caused by nuclear explosions occurred in the USSR. The study disclosed that one of the primary needs for more thorough investigations of world-wide seismicity is a more complete world-wide network of seismograph stations with standardized equipment.

A study of world-wide seismicity similar to the one for 1960 is currently being undertaken for 1963, using data from the US Coast and Geodetic Survey Standard Station Network. ★

NON-NEWTONIAN *flow studies*

1st LT JOHN L. SUTTERBY, Chemistry Research Laboratory, ARL

Liquid-rocket propellants commonly exhibit non-Newtonian flow properties. Hence, the Air Force is conducting research in non-Newtonian flow. This article describes the results of a recent investigation (3). Further details will be described in a series of three journal articles currently in preparation at the Aerospace Research Laboratories.

General Remarks. In the simple viscometric geometries, Newton's law of viscosity may be expressed as

$$\tau = -\mu\Delta \qquad (1)$$

in which the viscosity μ is a proportionality constant relating the shear stress τ and shear rate Δ. Gases and simple liquids (e.g. water) obey equation (1). Materials which do not obey equation (1) are called "non-Newtonian." Polymer solutions, molten polymers, suspensions, etc. are examples of non-Newtonian materials. For certain types of non-Newtonian fluids, the relationship between τ and Δ is described by the "generalized Newtonian" equation

$$\tau = -\eta\Delta \qquad (2)$$

in which η, the non-Newtonian viscosity, is a function of τ or Δ.

For molten polymers and polymer solutions, one commonly observes that η approaches a limiting value η_0 as Δ approaches zero, and approaches another limiting value η_∞ (less than η_0) as Δ becomes very large. For intermediate Δ, one commonly observes that log η is a linear function of log Δ for a wide range of Δ. A number of models have been proposed to describe non-Newtonian viscosity data. These are merely empirical functions of form $\eta = \eta(\tau)$ or $\eta = \eta(\Delta)$ which conform to one or more of the characteristics of viscosity data noted above. Each model contains adjustable parameters which are determined by curve fitting the model to viscosity data. Hopefully, these parameters can be used to predict the behavior of the fluid in other flow geometries. To do this, one first generalizes equation (2) as follows

$$\underline{\underline{\tau}} = -\eta\underline{\underline{\Delta}} \qquad (3)$$

in which $\underline{\underline{\tau}}$ is the stress tensor, and $\underline{\underline{\Delta}}$ is the rate of deformation tensor. The η model is converted to tensorially invariant form. (For details, see page 102 of reference 1.) Equation (3) is then substituted into the equations of motion (pages 84-86 of reference 1) to obtain the non-Newtonian analog of the well-known Navier-Stokes equations. For simple flow geometries, these equations can be solved. For complex geometries, dimensional analysis will indicate suitable dimensionless groups for correlating experimental data.

A warning note should be made concerning application of equation (3). Equation (3) can describe non-Newtonian viscosity, but can not describe other non-Newtonian effects, such as viscoelastic phenomena. Hence, equation (3) can be used safely only when such effects are negligible. Several experimental tests of equation (3) are discussed in a recent review article (2). These tests indicate that equation (3) is adequate for describing the steady flow of polymer solutions and molten polymers in a wide variety of geometries.

Converging Flow in Conical Sections. The remainder of this article summarizes the results of a recent investigation of converging non-Newtonian flow in conical sections. For further details, see reference 3.

Flow rate versus pressure-drop data were

taken in conical sections like that sketched in figure 1. The non-Newtonian fluids were aqueous solutions of Natrosol 250 H (a high-molecular-weight polymer). Cone-and-plate viscometer data were taken for each Natrosol solution. The limiting viscosities η_0 were

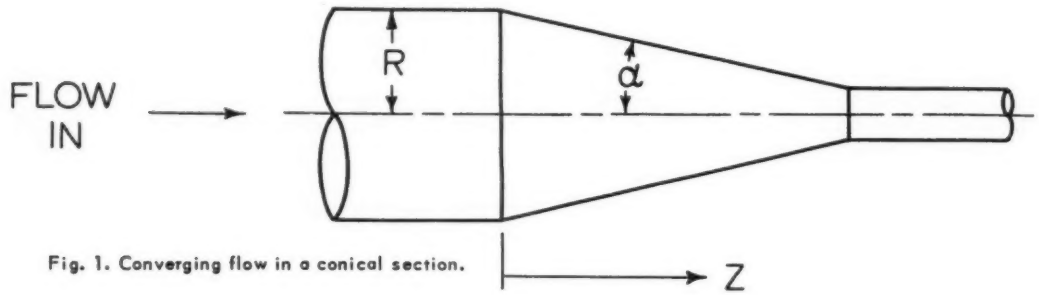


Fig. 1. Converging flow in a conical section.

estimated by analyzing falling sphere viscometer data. The viscosity data for each solution were fitted with a new viscosity model of form

$$\eta = \eta_0 \left[\frac{\text{arc sinh } (B\Delta)}{(B\Delta)} \right]^A \qquad (4)$$

in which A and B are positive parameters. This model gave a better fit of the data than previous models.

Because of the complexity of the converging flow problem, an exact solution relating pressure drop ΔP and flow rate Q could not be derived. However, it was possible to derive asymptotic solutions for the limiting cases of very-low and very-high flow rates. The low-flow rate asymptote is of form

$$\Delta P = \text{function of } (Q, \eta_0, A, B, \text{geometry}) \qquad (5)$$

The high-flow rate asymptote is of form

$$\Delta P = \text{function of } (Q, \rho, \text{geometry}) \qquad (6)$$

in which ρ is the fluid density. The sum of equations (5) and (6) is the simplest type of expression which might describe pressure losses over the entire range of flow rates.

$$\Delta P = \underset{\text{Eq'n (5)}}{\Delta P} + \underset{\text{Eq'n (6)}}{\Delta P} \qquad (7)$$

Equation (7) simplifies to equation (5) for small Q and to equation (6) for large Q. It reduces properly to the tube flow solution as the angle α (see figure 1) approaches zero.

Converging flow data for three Natrosol solutions are plotted in dimensionless form in figure 2. These data were all taken in the same conical section. The dashed curves are low-flow rate asymptotes drawn according to equation (5). The dotted line is the high-flow rate asymptote corresponding to equation (6). The solid curves are drawn according to equation (7). These curves describe the asymptotic behavior at low- and high-flow rates, and do a good job of describing data at intermediate-flow rates as well.

Equation (7) is recommended for estimating pressure losses for flow of Natrosol solutions in conical sections. A similar equation can be derived for any non-Newtonian fluid obeying equation (3). A straightforward procedure is outlined in reference 3. ★

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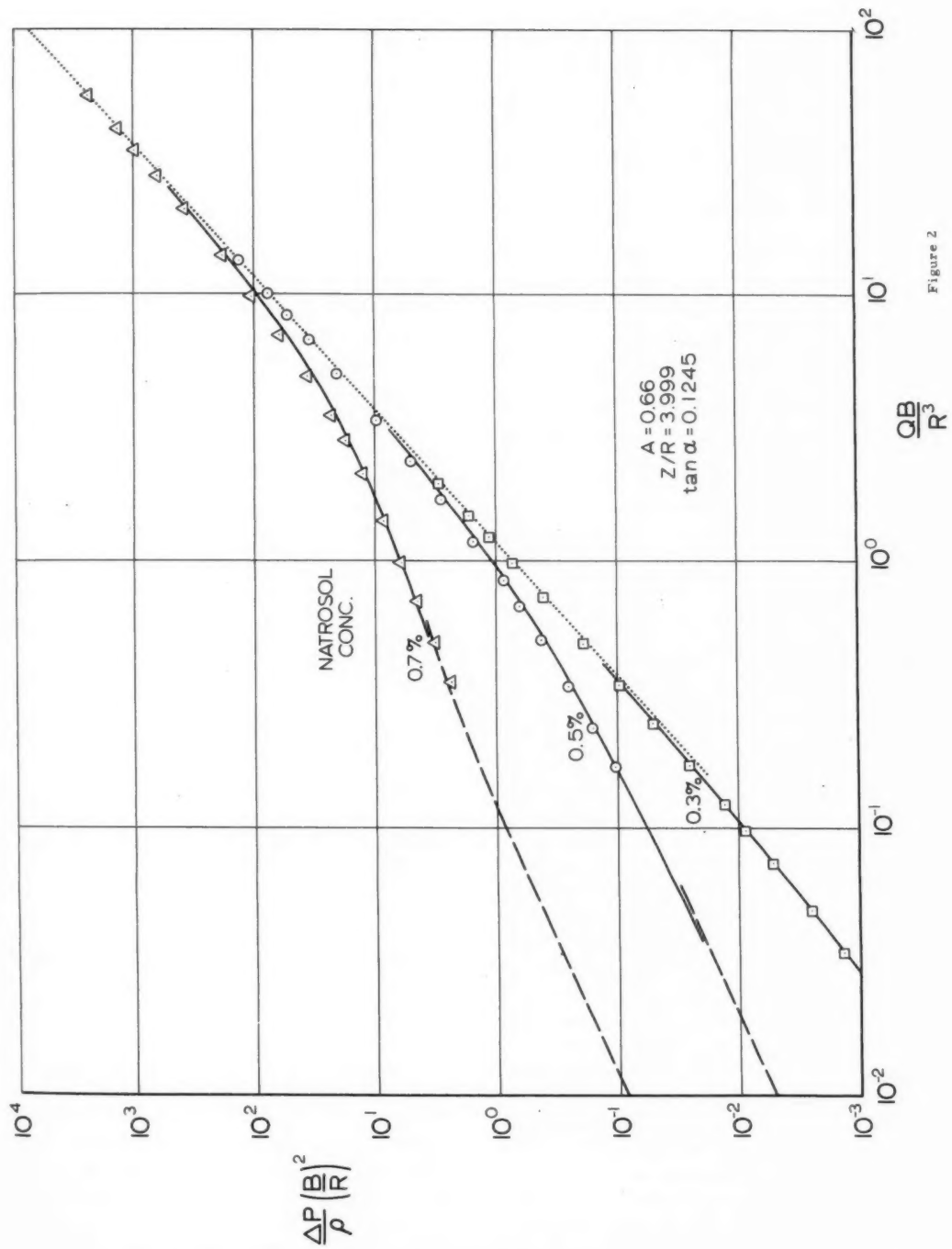


Figure 2

Fig. 2. Dimensionless pressure drop versus dimensionless flow rate for laminar non-Newtonian converging flow in conical sections.

a bibliography on functional equations*

CAPT JOHN F. GANDER
Directorate of Mathematical Sciences, AFOSR

This article is addressed to those who understand the meaning of each word in the title. When one sets himself the task of writing a bibliography, he is immediately faced with the problem of what should be included, and what should be excluded. Generally speaking, the flavor of a bibliography will, to some extent, take on the character of the author. This bibliography is no exception.

In order to compile this bibliography the author, Prof. Gyorgy I. Targonski of Fordham University, Bronx, N.Y., felt it necessary to adopt a definition of a Functional Equation. For the purpose of this bibliography, he adopted the definition by A. R. Schweitzer, as "Functional Equations in the proper sense" are those functional equations which are neither differential, nor difference, nor integral equations, nor a mixture of these--nor do they contain at all any differential, difference, or integral operators. Forewarned is forearmed; and that is precisely the function served by the first sentence of this article.

Admittedly, this definition does not describe a Functional Equation for everyone; but it does convey to those who are familiar with and make use of Functional Equations in their daily work a somewhat better picture of what to expect in this bibliography.

Unfortunately, even with this rather narrow "definition," many interesting fields were omitted to prevent the bibliography from becoming too voluminous, and also partly because some fields have become disciplines in their own right. Because of the close relation between the Theory of Functional Equations and Iteration Theory, papers on Iteration Theory were included in those cases where functional equations are involved in an essential and explicit way. On the border line between functional equations and algebra, the equations of distributivity, associativity and bisymmetry are included, while the more penetrating investigations, as the theory of continuous groups, form a complete study by themselves and are therefore omitted. A few papers in the field of stochastic processes originating in probability theory are included because of their exclusive reliance on a functional equation. The theory of generalized means is excluded, since solutions of functional equations play only a secondary role in that discipline. Number theoretical functions are also excluded. Picard's investigations in special functions defined by functional equations, and related work, are omitted more or less arbitrarily.

With all of these omissions, is there anything left? Yes! In this bibliography Prof. Targonski has included those papers which deal directly with the solution, under various conditions, of one or more functional equations. There are over 450 entries by 206 authors, from Abel to Zalts.

A very important feature of this bibliography is that it also contains a critical abstract of each paper designed to inform the reader concerning the problem treated, and to give the equation in question.

Without doubt, serious survey work of this kind will be of value to the mathematical community as well as to the users of mathematics. It should be encouraged. ★

* *Targonski, Gyorgy I., A Bibliography on Functional Equations, Fordham University, Bronx, New York. Prepared under AFOSR Contract No. AF 61(052)-602.*

SCIENTIFIC NOTES

Dr. John N. Howard Named AFCRL Chief Scientist: AFCRL has announced the establishment of the Office of Chief Scientist and, at the same time, has named Dr. John N. Howard to the newly created post. The Chief Scientist has the responsibility for advising the Commander, AFCRL, on existing and

planned AFCRL research programs. Dr. Howard was formerly Chief of the Optical Physics Laboratory and, since December 1963, has been Senior Scientist of that laboratory. He is the editor of the Journal of Applied Optics, and is a member of a large number of national and international scientific committees and panels. He joined AFCRL in December 1954 and, during the past 10 years, has helped to direct the rapid expansion of AFCRL's program in infrared. He has served as one of the Air Force advisors in matters relating to infrared transmission and detection. At one time he served as editor of the Journal of Infrared Physics. He received his Ph.D. from Ohio State University.

★ ★ ★

A limited number of copies of a brochure describing the research program of the Plasma Physics Research Laboratory, Aerospace Research Laboratories, are now available. Copies may be obtained by writing to: Aerospace Research Laboratories, ATTN: ARH, Wright-Patterson AFB, Ohio.

from basic research to application: a devious route

MAJ JOSEPH P. MARTINO
Assistant for Research Coordination, AFOSR

Is basic research of any value to the Air Force? The basic researcher will answer "YES" to this question almost by reflex. When pressed to cite examples, however, the basic researcher usually has some difficulty. This difficulty is traceable, not to the falsity of the YES answer, but to the devious routes which the results of basic research take as they work their way into Air Force application. Some of the difficulty the basic researcher encounters in trying to show how his results have been of benefit to the Air Force is illustrated below.

During the period 3-14 August 1964, the author attended a short course on "Status of Modern Control Systems Theory" at UCLA, Los Angeles, Calif. This course was run by Dr. Cornelius Leondes, who is a principal investigator on a grant from the Applied Mathematics Division, Directorate of Mathematical Sciences, AFOSR. The course is an excellent one, and provides considerable information on recent developments in control theory.

There were 10 guest lecturers who presented specific topics to the class. Of these 10, 4 had received their PhD degrees as a result of AFOSR support; 1 other had received support from AFOSR; and an additional 3 had received both PhD and postdoctoral support from AFOSR grants. The 2 remaining had received support from other Air Force agencies. Much of the material presented by these lecturers was based on the results they had obtained under AFOSR sponsorship.

Of the 52 persons attending, 22 were clearly associated with the aerospace industry, and another 15 with general industry, including computer firms. Two were from the Air Force and 8 from other government agencies. The remaining 5 were from educational institutions.

This course illustrates one of the problems of tracing the influence of the results of AFOSR-sponsored research. It would be difficult enough to prove that an engineer from an aircraft firm learned in this course about a certain technique developed under AFOSR sponsorship, and then applied it to an Air Force project. The connection between AFOSR sponsorship and the output of one of the students who attends a class taught by one of the educators present at the course is even more tenuous. In short, at this course a tremendous amount of AFOSR-sponsored research was disseminated to a large number of people scattered throughout government, industry, and the universities. When the results of this research show up in Air Force hardware, it is practically impossible for us to demonstrate any direct connection, and thus gain any credit for it. However, the course does illustrate that our research findings are disseminated effectively, albeit by hard-to-trace routes. ★

HURRICANE PREDICTION

METEOROLOGY LABORATORY, AFCRL

Meteorologists are hopeful that they will eventually be able to predict exactly when and where hurricanes will form. Dr. Louis Berkofsky of AFCRL's Meteorology Laboratory has recently shown that a mathematical model can give a realistic enough picture of hurricane formation to make such prediction possible.

Berkofsky's model consists of five equations which express relationships among five meteorological parameters. These are: the stream function, which gives the pattern of horizontal wind speed and direction at a given altitude; temperature; mixing ratio; vertical motion of air; and horizontal divergence. Of these, only wind speed and direction, temperature, and mixing ratio need be found by direct observation. The other quantities may be calculated from a knowledge of these observed parameters. Additional quantities in the equations, such as the amount of latent heat released by the condensation of water vapor, and frictional effects, may also be calculated.

From a set of initial observations of wind speed and direction, temperature, and mixing ratio, the equations are solved and the solutions are stepped forward a small increment of time (five minutes) to generate or "predict" new wind speed, direction, temperature, and mixing ratio which are in turn used to calculate new values for the five unknowns, and so on. The process can be carried on indefinitely by computer to predict what the wind speed, direction, and location of a hurricane will be at any given time after its formation.

The model itself is not new. Berkofsky first constructed it in 1957. At that time, however, it failed to generate a "mathematical hurricane" from the set of wind and temperature data that were used. Lack of the necessary data prior to hurricane formation was responsible for this failure. Berkofsky was forced to make assumptions about wind and temperature.

Then, by one of those fortunate accidents that sometimes result in scientific discovery, very complete wind and temperature data prior to the formation of a hurricane were finally obtained. Typhoon Doris formed in an area where very detailed weather observations were being made for a 1958 series of nuclear tests in the Pacific. From a recent report of these observations, Berkofsky learned that his assumptions about temperature had been incorrect. The temperature at altitudes where atmospheric pressure is 500 millibars (about 20,000 feet) above the tropical ocean regions (5–25 degrees north latitude), where hurricanes form, is an important factor in the equations. Berkofsky had assumed that the isotherms would follow the streamlines, and that the temperature would increase gradually from north to south. In reality the isotherms have a much more complex pattern prior to hurricane formation. With the data from Typhoon Doris, Berkofsky's model gave a picture of the hurricane's formation and movement which checked very well with what was actually observed. In fact, Berkofsky discovered that this temperature is probably the single most important parameter. Variations of only 1 or 2 degrees in 50 km can signal the formation of a hurricane if the isotherms display a certain characteristic pattern.

The speed of the cyclonic winds that develop is proportional to the temperature gradient in such a pattern. If they are too small, no hurricane develops. Berkofsky's model gave wind speeds that were somewhat higher than those actually observed for Typhoon Doris; but the rate of formation and the path which the model predicted were both in very close accord with those observed.

Although Berkofsky's model shows promise for reducing loss of life and property during hurricanes, two difficulties stand in the way of applying it to the prediction and possible prevention of hurricanes. The difficulty in prediction is that of continuously monitoring temperatures in the vicinity of 20,000 feet over the large areas where hurricanes can develop. The difficulty in prevention is that of destroying hurricane-producing temperature differences which extend over a very large volume of air. ★

Superconductivity of TELLURIUM

MAX SWERDLOW
Directorate of Physical Sciences, AFOSR

Superconductivity, a phenomenon found in many, but not all metals at temperatures near absolute zero, is the complete disappearance of electrical resistance resulting from a "condensation" of the conduction electrons into a state of frictionless motion. In simpler phrases, this says that a superconductor is a perfect conductor of electricity. Electrical current in a superconductor encounters no resistance to its flow. The superconducting condition occurs only at temperatures near absolute zero (0^{o} Kelvin, -273^{o} Celsius, -460^{o} Fahrenheit). Superconductivity has been observed only in metals and metallic alloys--conductors, never in an insulator or semiconductor. Dr. B. T. Matthias* and Dr. J. L. Olsen**, working at the University of California, San Diego, La Jolla, California, under AFOSR Grant No. 631-64, have observed a superconducting transition in tellurium at 3.3^{o} K at high pressures.(1) This is the first observation of superconductivity in an element of the sixth column of the nontransition elements in the periodic table. And it is the first time a semiconducting element has been turned into a superconductor without a crystallographic phase change.

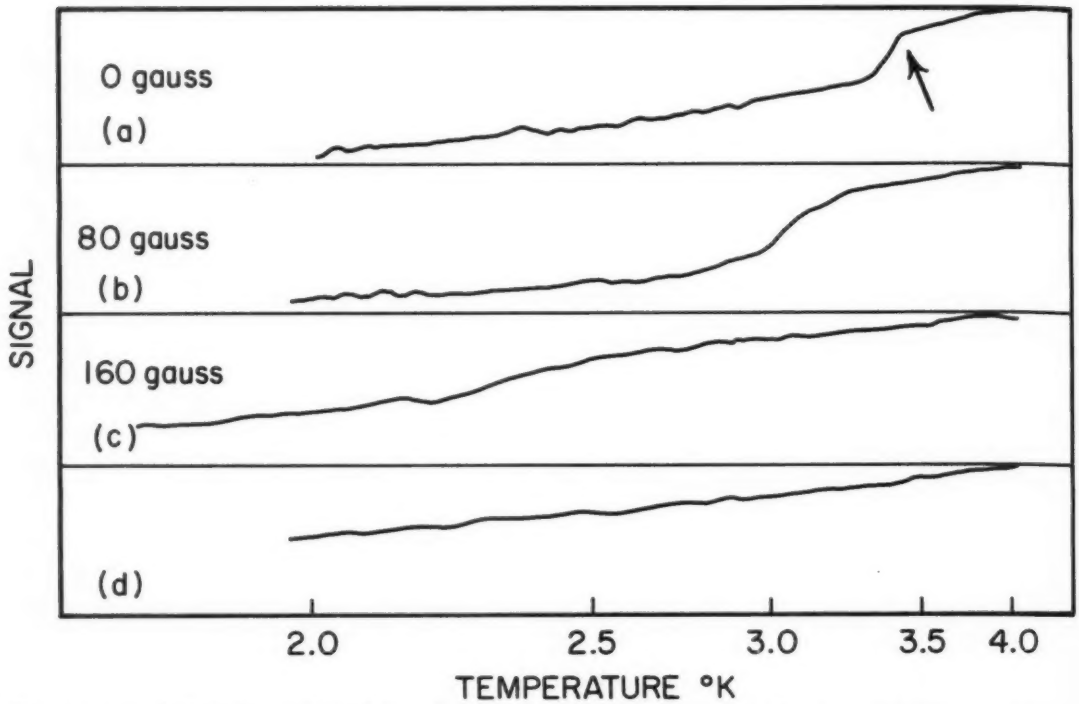
All this again supports the view that superconductivity is a rather general phenomenon.(2) To illustrate the importance of this discovery, let us review the current state of superconductivity. During the past few years, it has become increasingly probable that most metals will go through transitions at low temperatures. Below these transition temperatures, the conduction electrons will become strongly interacting, giving rise to such phenomena as ferromagnetism, antiferromagnetism and superconductivity. (At lower temperatures, that is to say, below 10 millidegrees Kelvin, there may be other as yet unknown transitions such as the ferromagnetism due to the nuclear moments.) At present, however, the superconducting transition seems to be by far the most general of all these ordering phenomena of the conduction electrons. In the superconducting state, electrons with opposite spins form pairs and thus give rise to a Bose condensation similar to He_4. In this state, the metal will be completely diamagnetic and an infinite conductor. Superconductivity will disappear as the temperature is raised above the critical temperature or the magnetic field above a so-called critical field, which is essentially nature's safeguard against excessive energy imbalances.

Many years ago, rules were developed by Matthias to predict superconducting transition temperatures strictly on the basis of the number of valence electrons.(3) Matthias' rules made it certain that, should any of the semiconductors like indium antimonide or tellurium ever become metallic, they would then also be superconducting. Indium antimonide, under pressure, goes through a polymorphic phase change and becomes isomorphous to white tin. In this form, researchers at the University of California, Los Angeles, working under AFOSR Grant 245-64 (Directorate of Chemical Sciences), did, in fact, find it superconducting.(4) Tellurium, however, has presented a different story. The pressures are much higher, and the transition to a metal seems to be a fairly gradual one.

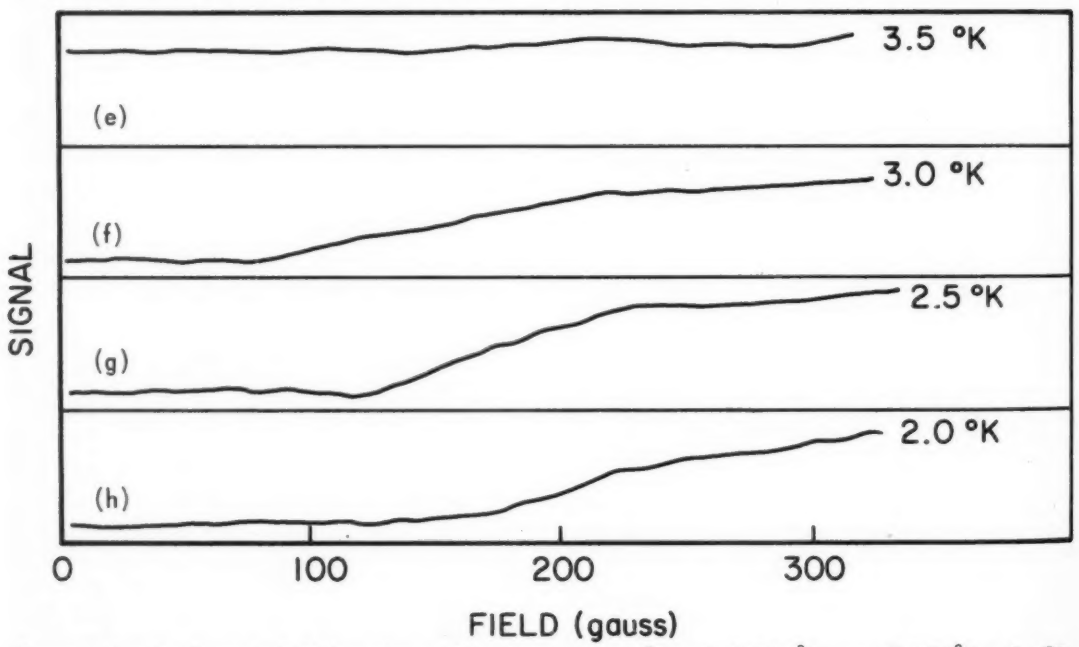
Professor Olsen built the pressure equipment described below in order to test tellurium and to check the hypothesis in this way. Pressure was applied at room temperature to thin tellurium disks of 99.999% purity, placed between truncated cones of tungsten carbide,

** Professor B. T. Matthias, Director of the Institute for the Study of Matter, is the recipient of the Research Corporation Award of 1962 in recognition of his outstanding achievements in the fields of superconductivity and ferroelectricity. For their discoveries of the greatest number of known superconductors and all of those materials used in superconducting magnets today, the Franklin Institute awarded Drs. B. T. Matthias and J. K. Hulm the John Price Wetherill Medal for 1964.*

*** Professor J. L. Olsen of the Federal Institute of Technology in Zurich, Switzerland, came to the Institute at La Jolla for a short stay earlier this year. Part of his work done at Zurich was sponsored by the Swiss Arbeitsbeschaffungsfonds des Bundes.*



Curves a, b, c, d: Temperature dependence of signal; - a, b, c: with Te; - a : H = 0; - b : H = 80 guass; - c : H = 160 gauss; - d : H = 0 with 80-90% of Te removed.



Curves e, f, g, h : Magnetic-field dependence of signal; - e : T = 3.5°K ; - f : T = 3.0°K ; - g : T = 2.5°K ; - h : T = 2.0°K.

using the clamp technique described by Chester and Jones.[5]

In Olsen's case, the cone-face area was 7 mm^2, so that the maximum applied force of 4 tons corresponded to approximately 56,000 atmospheres on the tellurium. This is well above the pressure of 45,000 atm. at which the resistivity of tellurium drops to that expected for a metal.[6] Superconductivity was detected by a low-frequency mutual-inductance method. The off-balance signal obtained from a bridge measuring the mutual inductance of a pair of coils containing the specimen was recorded as a function of temperature.

With pressures of approximately 0 atm., 28,000 atm. and 42,000 atm., no transition was observed; but transitions like that shown in Figure 1, curve (a), were seen in three separate specimens exposed to approximately 56,000 atm. Thus, the critical pressure seems to be between 42,000 and 56,000 atm. Transitions in the presence of magnetic fields parallel to the plane of the disk are shown by curves (b) and (c). On reduction of the pressure to approximately 42,000 atm., a small residual transition was observed in some cases, while further reduction of pressure resulted in complete disappearance of the transition. Curve (d) shows the signal with approximately 56,000-atm. pressure after removal of 80-90% of the tellurium specimen.

It should be noted that the pressure in a device of the type used is highly inhomogeneous and will increase towards the center of the specimen. This will lead to a reduction of transition temperature, T_c, towards the center of the plate if $\partial T_c/\partial p$ is of the sign observed in most superconductors. It is believed that this may be the cause of the very broad temperature transitions.[7]

The field-dependence of the bridge signal at various temperatures is recorded by curves (e) - (h). The transitions as a function of the field are badly smeared, as may be expected under the conditions of the experiment, which may well make the tellurium into a type-II superconductor. If the field at which a change in signal is first observed is H_{c1}, $H_{c1}(T=0) = 250 \pm 50$ gauss. ★

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Random-Noise Generation Methods

CAPT THOMAS K. BURGESS
Directorate of Information Sciences, AFOSR

The use of statistical methods to solve engineering problems is becoming more prevalent. A major difficulty in implementing some of these tools has been in generating random numbers or random noise. Present methods for generating random numbers or noise requires either large storage space in computers or else complex electronic devices.

Scientists at the University of Arizona's Hybrid Computer Laboratory have been able to solve this problem. They needed a simple random-noise generator which would work with their Arizona Statistical Repetitive Analog Computer (ASTRAC II), a hybrid analog digital computer. Mr. R. L. T. Hampton, a graduate student in electrical engineering, under the guidance of Dr. Granino A. Korn, and with the aid of a grant from AFOSR, did develop a simple hybrid analog-digital psuedorandom noise generator. Their device is basically a digital shift-register sequence

generator. These digital numbers may either be used directly, or they may produce binomial or normally distributed random noise. This shift-register procedure is completely independent of any physical quantities except for the clipping levels applied to the outputs.

The device can be run at a 4-megacycle clock rate, and will produce a 33,554,431-bit sequence before repeating. The sequence of bits generated has been shown to meet all the requirements of psuedorandomness. The power-density spectrum has a harmonic-frequency separation of 0.123 cycles per second, and a band width of 1.28 megacycles. Multiplexing is used to obtain 4 separate uncorrelated outputs.

The sequence is generated by using a single 25-stage shift register with feedback from the 3rd and 25th stages fed into the 1st stage through a Modulo 2 adder. Each of the 25 flip-flop stages has a reset switch so that initial conditions can be established. Multiplexing is accomplished by using every 4th bit for a single-channel sequence which generates 8,388,608 independent random bits in each channel. Analog noise is generated by a digital-to-analog converter consisting of filters and diode amplifiers. Longer strings of random numbers could be generated by adding more stages to the shift register.

With this simplicity of design and relatively inexpensive logic employed, conventional noise generators may soon be replaced by devices like this, and statistical sampling methods will become easier to use, thanks to the University of Arizona scientists. ★

Reference: American Federation of Information Processing Societies, 1964 Spring Joint Computer Conference Proceedings, Vol. 25, pp. 287-302. American Federation of Information Processing Societies, 1964.

Anomalous mobility in CdS crystals

1st LT KENNETH A. GALE, Solid State Physics Laboratory, ARL

Certain CdS crystals exhibit unusual properties at low temperatures. Their photoconductivity will change irreversibly as much as 12 orders of magnitude upon exposure to light with a wave length shorter than 6900Å. Thus, when these crystals are cooled to 77° K in the dark, they have a very low conductivity of the order of 10^{-15} mho/cm. However, upon exposure to light with a wave length shorter than 6900Å, the conductivity increases by as much as 12 orders of magnitude, and the conductivity remains high when the light is extinguished. The crystals may be returned to the low-conductivity state by warming them to about 250°K and then recooling them in the dark. This type of CdS crystal is referred to as a "storage" crystal to distinguish it from the "normal" CdS crystal which does not exhibit this property.

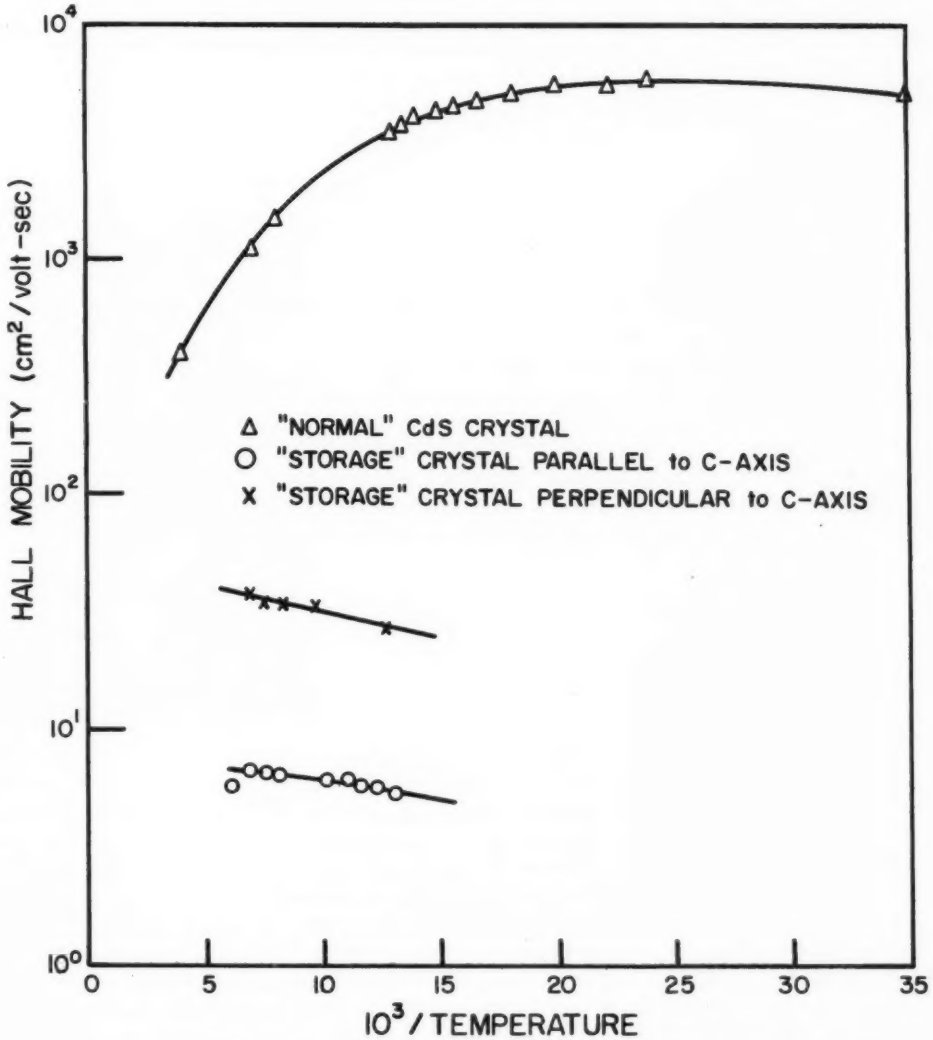
We have studied the Hall mobility of these "storage" crystals in the high-conductivity state in the temperature range from 4.2° K to approximately 250°K.

The Hall mobility measurements are made using a dc - dc method with 5 probes on the crystal. The probes are applied to the crystal using indium solder and an ultrasonic soldering iron. Using the 5-probe method, we are able to cancel out any effect of the applied voltage, so that the voltage measured on the Hall probes is the actual Hall voltage. Also, using this method, it is possible to measure the resistance of the crystal without introducing an appreciable error due to the contact resistance. The voltage-sensing devices used in this setup limit our ability to measure the Hall mobility to those crystals which have a resistivity of approximately 10^5 ohm-cm or less.

The mobility of these "storage" crystals, both perpendicular and parallel to the C axis, is compared to the mobility of a "normal" CdS crystal in the accompanying figure. The "normal" CdS crystal characteristically exhibits a mobility which first increases, then levels off, and finally decreases as the temperature of the crystal approaches liquid-helium temperature. The mobility of the "normal" crystal in the figure probably decreases to 50 $cm^2/v.$ sec at 14° K. In contrast to this, the "storage" crystal characteristically exhibits a mobility which is very low and constant with temperature. Another

phenomenon which is characteristic of the mobility of the "storage" crystal is the anisotropy of the mobility relative to the C-axis of the crystal. The mobility perpendicular to the C-axis is approximately 10 times higher than the mobility parallel to the C-axis in all of the storage crystals that we have measured. Previous measurements in this laboratory show that the mobility of a "normal" CdS crystal is isotropic relative to the C-axis at least within the 10% accuracy of the measurements.

Examination of the crystals used in these measurements revealed no visible crystal inhomogeneities or faults which would contribute to the anisotropy of the mobility. A possible explanation for the low mobility and for the anisotropy of the mobility would be either impurity band conduction or impurity scattering. At the present time, work is continuing to determine the cause of these properties of "storage" crystals. ★



TEMPERATURE DEPENDENCE of the HALL MOBILITY

OAR profiles

Dr. Yoon Soo Park has been a research physicist with the Solid State Physics Research Laboratory, ARL, from 1962 to the present. Prior to that, he was a research physicist with the D.H. Baldwin Company, a teaching assistant at the University of Alberta, and an instructor at Pusan University. He has a B.S. in Physics from the Seoul National University (1952), an M.S. in Physics from the University of Alberta (1955), and a Ph.D. in Physics from the University of Cincinnati (1963). He also has a number of publications to his credit. Currently, he is conducting research on the optical electrical properties of II-VI-compound semiconductors. In this issue of the Review, he writes on "Excitons in the Photoconductivity of CdS."

First Lieutenant Kenneth A. Gale is a Nuclear Research Officer at the Solid State Physics Laboratory, ARL. He has an A.B. in Physics from Kenyon College (1961) and an M.S. in Nuclear Engineering from the Air Force Institute of Technology (1963). In this issue of the Review, Lt Gale writes on the "Anomalous Mobility in CdS Crystals."

First Lieutenant John L. Sutterby is a chemist with the Chemistry Research Laboratory, ARL. His education includes a B.S. from the University of Missouri (1958), and an M.S. from the University of Wisconsin (1959), both in Chemical Engineering. He has previously had a research fellowship with the University of Wisconsin, and has worked for the Esso Research and Engineering Company. At present, he is studying the effect of a fluctuating pressure field on a burner flame. In this issue of the Review, Lt Sutterby writes on "Non-Newtonian Flow Studies."

Mr. Bernard A. Silverman is a research physicist with the Cloud Physics Branch, Meteorology Laboratory, AFCRL. He has a B.S. in Meteorology from the City College of New York (1953) and an M.S. in Meteorology from the University of Chicago (1958). Mr. Silverman has been with AFCRL since 1956. He is presently Project Scientist for the Weather Modification Project (Project 7605), and is currently working on the warm fog research and modification program. He has contributed to the development of a method and apparatus for suppressing jet-aircraft condensation trails, and is coinventor of a patent (pending) on this work. Mr. Silverman has a number of publications to his credit, and is a member of the American Meteorological Society and the American Geophysical Union. His work at the Meteorology Laboratory was described in an article in the November 1964 issue of the Review, "Atmospheric Limitations on Laser Propagation."

Mr. Caldwell P. Smith, an electronics engineer, is Chief of the Digital Speech Compression Branch, Data Sciences Laboratory, AFCRL. Currently, he is doing research in speech–compression techniques for voice communication to reproduce speech data with special synthesis facilities using vocoders. He attended Baylor University, Waco, Texas, from 1936-1939, Air Force schools in communications and radar in 1941, and the Harvard MIT Electronics and Radar School from 1944-1945. He joined the Communications Sciences Laboratory (in 1946) at what later became AFCRL, and has specialized in speech research since 1949. Mr. Smith has a number of publications to his credit. He is a member of the Acoustical Society of America, and received the Fulbright Award in 1954. His work at the Data Sciences Laboratory was described in an article in the November 1964 Review, "New Speech–Synthesis Technique."

Dr. Edward M. Dewan, a biophysicist with the Microwave Physics Laboratory, AFCRL, is currently working on the nonlinear multispectral analysis of cortical and subcortical E.E.G. data, the experimental investigation of E.E.G. entrainment effects, and other investigations. He has a B.S. (magnum cum laude) from Duke University (1953) and a Ph.D. from Yale University (1957). He first came to AFCRL in 1957. From 1961-1963, through special arrangement with AFCRL, he was a Research Associate at the Department of Physics, Brandeis University, Waltham, Mass. He won the 1963 OAR third prize for his paper, "Nonlinear Oscillations and Electroencephalography," and the first prize by the Aerospace Educational Foundation at the 10th Annual Air Force Science and Engineering Symposium, October 1963, USAF Academy, Colorado, for the same paper. Dr. Dewan has a number of publications to his credit, and is a member of Phi Beta Kappa and the American Physical Society. He wrote on "Communication by Brain Waves" in the November 1964 Review.

ULTRASOFT X-RAY ASTRONOMY

DR. MARSHALL C. HARRINGTON
Directorate of Physical Sciences, AFOSR

Professor Burton L. Henke of Pomona College, California, has adapted his laboratory methods in the ultrasoft X-ray region (wave length 5 to 20 angstrom units) to the measurement of X rays from the sun. His previous success in the microanalysis of light elements in small samples was reported in the OAR Research Review, No. 20, 17 December 1962. Professor Henke spent the past academic year at the Los Alamos Scientific Laboratory, while on leave from Pomona College, designing and carrying out experiments in X-ray astronomy. Since radiations of this wave length do not penetrate the atmosphere, it was necessary to carry the instruments to high altitudes by means of rockets.

The objective of the experiment was to obtain for the first time precise measurements of characteristic line intensities from the hydrogen-like and helium-like spectra of highly ionized carbon, nitrogen and oxygen atoms, that is, when these atoms are stripped down to one- and two-electron systems. These nearly completely ionized states are most probable in the sun's corona, and their relative populations are a measure of the one-to-two-million-degree temperature of this plasma. Eight principal line radiations were measured in the wave-length region 16 to 40 angstroms. These lines were considered to be of optimum usefulness in the present important efforts to explain the mechanism by which the coronal plasma reaches such high temperatures. The measurements are of particular importance during the present year--the Quiet Year of the Sun--to establish a reference base for the period of enhanced activity that the sun will soon be entering.

Another purpose of the experiment was to demonstrate the feasibility of using relatively inexpensive, spin-stabilized, ballistically pointed rockets for solar X-ray spectroscopy. The rockets employed were six Nike Tomahawks which were flown during May, July and August, 1964, from the Island of Kania, as part of our readiness program for use in the event the space testing of nuclear devices was resumed.

In this series of experiments, the pay load of the rocket contained 8 fixed-station, curved-crystal spectrometers with resolution adjusted to accept single X-ray lines when possible, or close-lying related lines where necessary. Mica and lead-stearate-decanate crystals with spacings of 19.9 and 100 angstroms, respectively, were used, and acceptance apertures were approximately $2^{o} \times 5^{o}$. The photons were counted with thin-window, continuous-flow Geiger counters, and the accumulated counts from each of the 8 channels were transmitted to the ground station every quarter second. The rockets, aimed directly at the sun at launch, were spin-stabilized at a nominal speed of 6 revolutions per second, and attained altitudes of approximately 300 km. Acquisition of data was possible for pointing errors up to 5 degrees. A stroboscopic sun sensor in the pay load provided precise knowledge of the sun's direction at all times. Typical values for fluxes observed in the Lyman-Alpha-like lines of C VI, N VIII and O VIII were 2×10^{8}, 2×10^{6} and 2×10^{6} photons/cm^{2} sec, respectively.

These experiments were designed by Professor Henke in collaboration with Dr. Harold Argo, Dr. James Bergey and Mr. Michael Montgomery of the Los Alamos Scientific Laboratory. The availability of the rockets, and the launchings were arranged by the Sandia Corporation of Albuquerque. The Air Force contribution to this research was the experience of Professor Henke who developed many of the special techniques employed under an AFOSR grant at Pomona College.

The results of this research were first reported at the Western National meeting of the American Geophysical Union, Seattle, Washington, December 1964. ★

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